Test & Training Enabling Architecture's Report on the Edwards AFB-China Lake ATM Test & Demonstration

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Introduction:

An Asynchronous Transfer Mode (ATM) test and demonstration was conducted with General Telephone (GTE), the Naval Weapons Center (NAWC-WP) at China Lake , California, and the Air Force Flight Test Center (AFFTC) at Edwards Air Force Base(AFB), California. The goal was to determine and demonstrate the feasibility and practicality of transporting range data to other bases using ATM technology. The ATM link consisted of two ATM switches, one located at the China Lake's control center and the other at Edwards 'Ridley Mission Control Center. The switches were connected together at the optical carrier (OC)-3 rate of 155Mb/s by GTE's and the 95th Communication Squadron's Synchronous Optical Network (SONET) networks.

As networks become more strategic to testing and training in the Department of Defense, current technology will have to evolve in order to meet new demands of interoperability between ranges and traffic growth. Dedicated links waste too much bandwidth, are inflexible, and cost too much. Router based topologies cannot provide adequate throughput performance and Quality of Service (QoS). ATM holds the promise of providing the needed performance, QoS, security, and cost efficiencies through switched technologies.

DISCLAIMER

> *This test was conducted with very little funding and was only made possible by the generous free use of the GTE ATM switches and fiber. However, the ATM switches that were used were four years old with outdated hardware and software. Some desired test equipment and interfaces were also not available for this test. Due to funding restrictions, only equipment on-hand or available for loan to the Government was used. Many people contributed to the success of this test, however, nobody was assigned to this test on a full time basis. The test had to be scheduled around our primary jobs, flight test missions, TDYs and a host of other obstacles. Even with all of these limitations, the test was very successful and was a great learning experience for both ranges. The link was planned, installed and tested in just over a two month period between February and April 1997. If a project was required to install a permanent ATM link, other equipment more appropriate to the range's needs would be purchased.*

Objective:

The objective of this test was to determine how well the ATM switches could transmit several different types of data to support interoperability of testing between two test ranges. Our focus was on the QoS provided by the ATM link, in particular, bandwidth performance, latency and bit-error-rates. We made assumptions based on the use of the existing Data Acquisition and Transmission System (DATS) (an existing microwave system between China Lake, Edwards AFB and Vandenburg AFB) that certain types of signals will require transport between China Lake and Edwards. The types of signals to be tested were;

- Serial Data (T-1s,TSPI, Timing, etc.)
- Voice
- Video

- Networks
- Telemetry

- Figure 1 shows the ATM Test Configuration.
- **T1 Circuit Emulation Test**

A T1 circuit linked two Digital Access and Cross-connect System II (DACS II) at China Lake and Edwards transported over the ATM switches. Both of the existing DACS at China Lake and at Edwards are used for voice and low speed RS-232 data switching. Voice and data links were established between the two DACS with few problems but during integration, the T1 experienced synchronization problems most likely due to the timing of signals. Due to the short duration of the test, time was not dedicated to resolving this problem but rather on collecting data on other range applications of ATM. With that exception, the performance and quality of the signal was excellent. Voice and TSPI data were exchanged successfully between the two locations throughout the test period. In addition, latency measurements were taken in several different configurations.

Two different round-trip delay measurements were made between Edwards and China Lake over the T-1. The first was using radar data with the loop back at the low speed interface of a channel bank. The delay was about 20 msec. The second measurement was made using a Bit Error Rate Tester (BERT) at 56 Kbps by cross-connecting to channels within the China Lake DACS. The trip delay measurement in this configuration was 12.9 msec.

Video Test

The Newbridge switch has a Joint Photographic Experts Group (JPEG) compression plug-in card. The video link was used in support of Joint Direct Attack Munitions (JDAM) mission. The encoding rates used were 37 and 80 Mbps. The JPEG video quality was acceptable when at least 20 Mbps of bandwidth was allocated, artifacts became noticeable at lower data rates. One peculiarity was observed, video from a spectrum analyzer was not able to be transmitted at any rate without distortion but other video signals had no problems. Motion Picture Expert Group II (MPEG-II) cards are now available on newer switches that reduce the required bandwith to a tenth.

Ethernet Network

The network tests proved successful. Ethernet was used because the ATM switch did not have any other interfaces available and no other ATM equipment was available. A full 10 Mbps was assigned to the Ethernet connection. Three applications were run: the Test and Evaluation Command and Control System (TECCS) and the Range Computational Control System II (RCCS II) and a pair of SGI Indy workstations were connected to test the Ethernet link. The bus topology of the Ethernet is shown in Figure 1.

Figure 1 Ethernet Test Configuration

The Test and Evaluation Command and Control System (TECCS) was connected to the ATM network and was able to display Time, Space Position Information (TSPI) tracks generated at China Lake. The RCCS II System was used to demonstrate how test data generated at one range could be monitored and processed at another range in near real-time. JDAM tests were supported at China Lake and monitored at Edwards by the customers using this ATM link.

The RCCS II System comprises the hardware and software required to perform three major functions; (1) Computational Function (CF), (2) Display Function (DF),and (3) Operator Control Function (OCF). The RCCS II System Software receives tracking, source, and status data and processes it to provide real-time displays. These displays permit project engineers and range safety controllers to effectively evaluate the events of on-going tests and to control a test mission. The data is displayed in the form of 2-D and 3-D maps, EU parameters, participant tracks, operator selected plot displays, video images, and various hard copies. It was observed that using multiple workstations on the ethernet network at the same time slowed all transfers on the ethernet bus. The RCCS II worked fine with no other traffic but impacted the other workstations when in use.

Using the SGI Indy Workstation, ping tests were done across the Ethernet/ATM link to determine the round-trip delay. The following results were recorded.

Payload Size (bytes)	Packets/Second sent/received	Round Trip Time (msec) min/avg/max	Percent Utilization	Percent Packet Loss
64	220/220	5/5/64	7	0
512	111/111	9/9/17	19	0
1,024	98/98	14/16/366	32	0
4,096	96/12	32/171/364	45	68

Table 1 - BI-DIRECTIONAL (CONCURRENT) DATA TRANSFERS

Telemetry to ATM Direct

Of all the types of signals required by ranges, telemetry has been the most difficult to transport. This is due to the non-telephony rates and format. Originally, EMR 8245 smart muxes were planned to be used with the ATM switches to transport the Pulse Coded Modulation (PCM) telemetry data streams across the ATM link. However, the older Newbridge switches were not able to provide DS-3 emulation. Instead, two ADC Kentrox ATM Access Concentrators-3 (AAC-3) were borrowed to test the direct translation of telemetry to ATM. The AAC-3 were connected through a T3 User Network Interface (UNI) card in the Newbridge switch. Two approaches were used during this test, BERT and tape playback. Two types of tests were conducted using the BERT. First running the BERTs with independent clocks, then using a "manual" clock correction.

BERT with independent clocks

This test was to determine the performance of the ATM system to manage two independent clocks at the receive and transmit interfaces. The test configuration is as shown in Figure 2. Two Firebird 6000A BERTs were used to generate and receive data at equal rates and known pattern (Quasi-Random Signal Source [QRSS] was used). The AAC-3 has two timing modes on its RS-530 interface, system clocking which only provides standard telephony data rates and port clocking which provides for any data rate – as long as the clocks are synchronous. The BERTs were both set to run using internal clocks and the AAC-3s were set to port clocking.

Running the BERTs at various rates, the port speed limit of the AAC-3 was found to be between 4.2 and 4.5 Mbps. The bad news is that when the network elements are not synchronized and the BERTs are free running (simulating telemetry), pattern resynchronizations occur regularly. Tests were performed at three different data rates 1, 2, and 3.8 Mbps. The following table summarizes the results:

Data Rate	Start Time	Stop Time	Time between Losses Average	Time between Losses Std Dev	Number of Losses
3.8 Mbps	14:39:45 7-Apr-97	6:26:25 8-Apr-97	0:04:59	0:00:04	189
2 Mbps	12:43:33 4-Apr-97	5:41:49 7-Apr-97	0:09:31	0:02:11	402
1 Mbps	14:09:52 8-Apr-97	5:21:08 9-Apr-97	0:20:16	0:03:47	44

Table 2 - BERT Test Results for Various Data Rates, with Independent Clocks

The probable explanation for the resynchronization is the AAC-3 output buffer. This output buffer tries to run at about half full. Since the clocks are different rates, the buffer is constantly filling or emptying based on the clock relationship. When a limit of the buffer is reached, the buffer resets to the center, causing a loss of data and a momentary drop in data. When the buffer is reset to half, the data is output again and the BERTs resynchronize.

BERT with clock correction

The purpose of this test is to control the clock on the receive end of the circuit to emulate a telemetry transmission system. Figure 3 shows the test setup for this procedure. This configuration provides for a free running clock (in an aircraft instrumentation package) transmitting a serial data stream through a transmission system to the processors. By controlling the clock at the receive end, a corrected timing signal can be provided to the AAC-3 to gate the data out at a rate much closer to the initial clock rate, therefore keeping the receive buffer from overflowing or underflowing.

To complete this test, a measurement must first be made to determine the frequency offset of the two BERTs (or transmitter and receiver in a telemetry scenario). In practice, comparing the telemetry output rate to a rate traceable to Universal Time Coordinated/Global Positioning System (UTC/GPS) could do this. By knowing the offset, it is possible to drive the output of the AAC-3 at the rate required to keep the buffer from overflowing or underflowing.

The measurement in this case was done between the two BERTs. The "telemetry transmitter" BERT was set to internal timing while the "telemetry receiver" BERT was externally timed from the first. In this configuration, the ATM circuit appeared to run error free (as expected). The "telemetry receiver" BERT displayed the "receive frequency" compared to its internal oscillator, in this case it was 3 Hertz (Hz) over the test data rate (4.2 Mbps). An external frequency generator was then connected to the "telemetry receiver" BERT to adjust the clock to use the previously recorded frequency offset. In practice, the transmitter data rate should be compared to a very accurate reference at the "transmitting site" and a very accurate reference (i.e., GPS) used for the correction at the "receiving site."

The test duration was 16 hours using the "Elapsed Seconds" field of 57,600 seconds. Four pattern losses occurred and two data losses. This was due to two separate sync losses that occurred at 19:38 and 2:48 during the test period. This indicates the frequencies were offset slightly and a sync loss would probably occur every 7 hours or so. This test supports the theory that the sync loss in the free running scenario is due to frequency offset rather than clock drift between the transmitting and receiving end of the ATM network. The ATM receive buffer will compensate for frequency drift around a center frequency or small change in magnitude over a given time period.

The results of this test were successful. This link ran error free for over 6 hours. This equates to an average bit error rate (BER) better than 10^{-10}. These results are good enough to support the telemetry requirements of the flight test community. The next step is to integrate bit synchronizers and provide an end-to-end capability between China Lake and Edwards.

Telemetry Tape Playback

After the BERT testing was completed, an attempt to run telemetry data through the system was attempted. An F-16 baseline tape was used to run data from a recorder to a bit synchronizer feeding the AAC-3. Figure 4 shows the test configuration. The test was cut short fairly quickly when the output from the tape recorder was found to drift several hundred Hz. The data rate of the test tape was 256 kbps. When measured on test equipment, the frequency was found to drift from 255,500 to 255,900 Hz. The whole concept of reconstructing the clock externally is based on a stable reference (within a few Hz, worst case). This test setup did not work when transmitted through the ATM network. However, the decom directly connected to the output of the tape recorder kept frame sync without a problem. The decom was displaying a received frequency that was also changing several hundred Hz. This indicates that any solution for this transmission problem must meet the IRIG 106-96 specifications for clock stability.

Conclusion:

The ATM test and demonstration was a success. We showed that telemetry, voice, video, TSPI, and network data can be carried over a single ATM link. Actual test missions were supported by the ATM link. The OC-3 was enough bandwidth to transmit all of the signals simultaneously.

MPEG encoding will allow 10 times more. The delay across the ATM network was outstanding, less than 10ms for the 100 mile run. The bit error rates were excellent once clocking problems were solved. Outdated equipment and a tight schedule limited the depth in which we could study the ATM technology. Encryption of the data was discussed buy not tested. More testing and study is needed to further examine the quality of service especially across a more complicated and congested network, clock recovery, encryption of data, time correlation between multiple signals, supportability, and costs.

ATM has a place in the test community. ATM gives the ability to transport multiple types of data over a single link and manage the bandwidth efficiently. Using ATM allows the user to trade off quality of service versus number of circuits. This flexibility does not exist For instance, instead of running video at 20 Mbps, the user may trade-off high quality video and use only 5 Mbps, then add a network connection of 10 Mbps and a telemetry stream at 5 Mbps while maintaining the same aggregate bandwidth. Since ATM can run over several different transport layers, bandwidth is not a problem. If an OC-3 is not enough, you can upgrade to an OC-12 or OC-48 and get 4 or 12 times the bandwidth. ATM also allows more efficient use of bandwidth because bit stuffing is not necessary and unused time slots are not transported.

A problem for ATM is the lack of QoS guarantees going over a public ATM network. This standard is still being worked. Virtual private networks can solve this problem but the cost goes up. The second problem for ATM is the clock reconstruction issue for telemetry. Several solutions are possible. The ideal solution is for access equipment into an ATM network specifically for telemetry that would perform clock reconstruction. Real-time support could be supported today provided the clock stability driving the instrumentation package is stable enough. To ensure this stability, slaving the instrumentation clock source to GPS is recommended. By slaving the clock source to GPS, the manual reconstruction issue may disappear allowing a GPS synchronized clock source to drive the output of the AAC-3 (in the case of this test). A Small Business Innovative Research topic has been submitted by the Air Force Flight Test Center to investigate ATM access equipment capable of performing clock reconstruction. In addition to clock reconstruction, the end equipment should support multiple data streams, inverse multiplexing, and T-3 UNI interfaces.

More detailed test reports and information is available upon request.

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